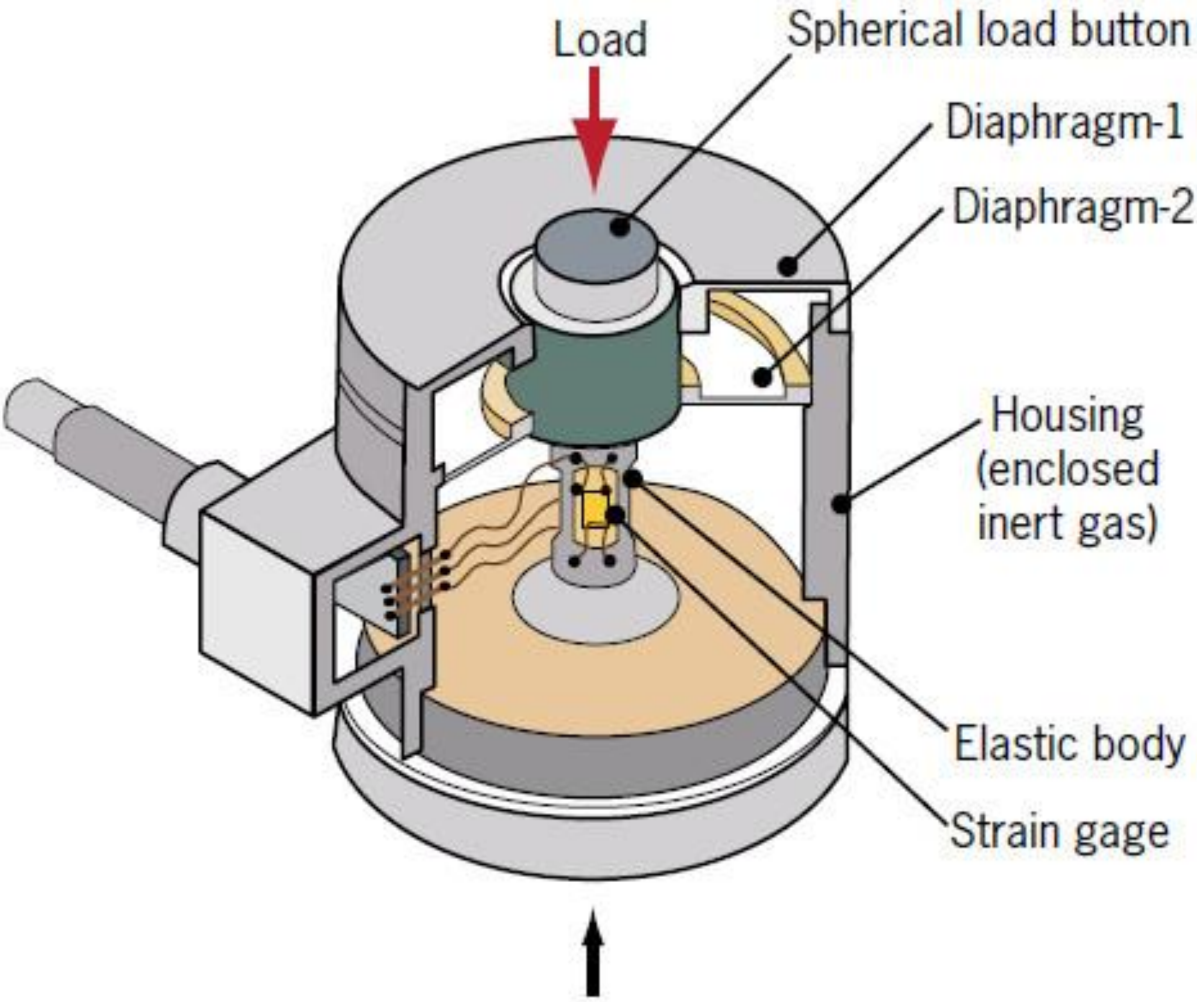


STRAIN GAUGE

MECHANICAL ENGINEER NZHO MAHDI 26/03/2025

Content:

Introduction:

Through my work in the past years in the field of truck scales maintenance and special courses, I would like to explain to you the role of the presence of these scales in controlling the quality of roads and not damaging them, and protecting the surrounding environment.

And also its role in trade and industry to satisfy the customer and consumer alike, and this is my conclusion:

Safe operation: Truck scales help measure and evenly distribute loads, ensuring safety during transportation in cities.

Reduced maintenance and fuel costs: Overloading vehicles leads to accelerated wear and tear on parts and increased fuel consumption. Measuring loads with a truck scale can prevent overloading, making it a worthwhile investment in the long run.

Compliance issues: Truck scales help the transportation company keep the weight of the vehicle under the specified safe limit, ensuring the safety of the driver and other people on the road. They also help the company avoid penalties that can reduce the company's profits.

REVIWE:

Stress and **strain** are fundamental concepts in materials science and mechanical engineering that describe the behavior of materials when subjected to external forces or loads. Here's a breakdown of each concept:

Stress:

Stress is the force per unit area applied to a material. It measures how much internal force develops within a material when it is subjected to an external load. Stress is typically measured in **pascals (Pa)**, which are equivalent to **newtons per square meter (N/m^2)**.

There are different types of stress based on the direction and nature of the applied force:

- **Tensile Stress**: When the material is being pulled or stretched.
- **Compressive Stress**: When the material is being compressed or squeezed.
- **Shear Stress**: When the force is applied parallel to the material's surface, causing it to deform by sliding.

Formula for Stress:

Stress=Force (F)Area (A)\text{Stress} = \frac{\text{Force (F)}}{\text{Area (A)}}

Where: F is the force applied (in newtons),

A is the cross-sectional area over which the force is applied (in square meters).

Strain:

Strain is the measure of the deformation or displacement of a material when it is subjected to stress. It is a dimensionless quantity (i.e., it has no units) because it is a ratio of the change in dimension to the original dimension of the material.

There are several types of strain, depending on how the material deforms:

- **Tensile Strain**: Change in length divided by the original length (for stretching or elongation).
- **Compressive Strain**: Change in length divided by the original length (for compression or shortening).
- **Shear Strain**: The angular deformation when the material is subjected to shear stress (measured in radians).

Formula for Strain: Strain=ΔL / L0

Where:

- ΔL\Delta L is the change in length (in meters),
- L0 is the original length (in meters).

Relationship Between Stress and Strain:

The relationship between stress and strain in a material is typically linear within the **elastic region** (where the material returns to its original shape after the load is removed). This relationship is defined by **Hooke's Law**:

σ=E·ε\sigma = E \cdot \varepsilon

Where:

- σ\sigma is the stress,
- EE is the **Young's Modulus** (a material property that measures the stiffness of the material),
- ε\varepsilon is the strain.

In the **elastic region**, the material deforms proportionally to the applied load. However, once the material exceeds its elastic limit (yield point), the material may undergo permanent deformation (plastic deformation) and no longer return to its original shape.

Types of Stress-Strain Behavior:

1. **Elastic Deformation**: When stress and strain are proportional (within the elastic limit), the material returns to its original shape when the load is removed.
2. **Plastic Deformation**: When the material is stressed beyond its yield point, it undergoes permanent deformation, and it does not return to its original shape.
3. **Fracture or Failure**: If the stress continues to increase, the material eventually reaches a point where it breaks or fails, known as the ultimate tensile strength or breaking point.

Stress-Strain Curve:

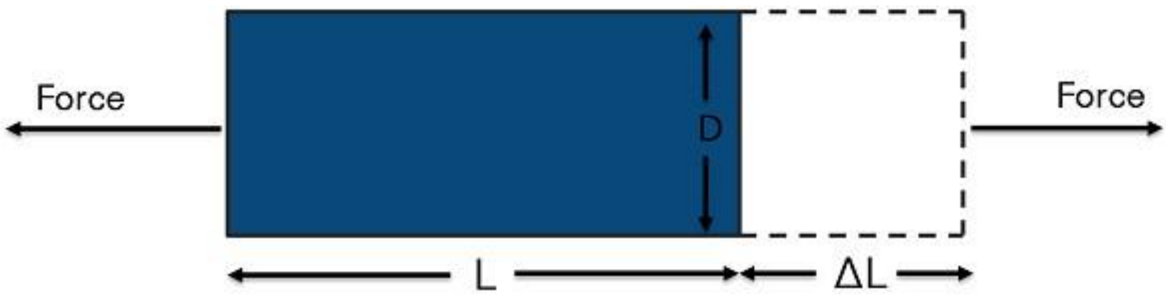
A typical stress-strain curve for a material shows the relationship between stress and strain as the material is subjected to increasing loads. Key points on the curve include:

- **Proportional Limit**: The point where the material stops following Hooke's Law (the relationship is no longer linear).
- **Elastic Limit**: The maximum stress that a material can withstand and still return to its original shape.
- **Yield Point**: The point at which the material begins to deform plastically.
- **Ultimate Strength**: The maximum stress the material can withstand before it starts to fail.
- **Fracture Point**: The point where the material breaks.

In summary, **stress** is the force applied to a material, and **strain** is the resulting deformation. Their relationship is crucial for understanding how materials behave under various loads and is essential in designing safe and durable structures.

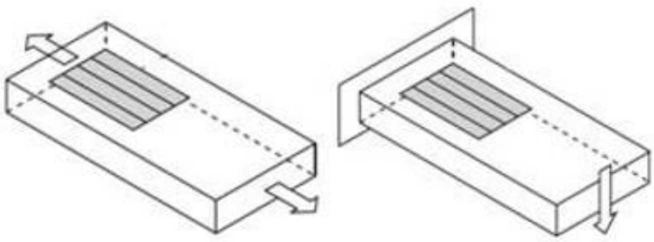
What is Strain?

In mechanical testing and measurement, you need to understand how an object reacts to various forces. The amount of deformation a material experiences due to an applied force is called strain. Strain is defined as the ratio of the change in length of a material to the original, unaffected length, as shown in Figure 1. Strain can be positive (tensile), due to elongation, or negative (compressive), due to contraction. When a material is compressed in one direction, the tendency to expand in the other two directions perpendicular to this force is known as the Poisson effect. Poisson’s ratio (v) is the measure of this effect and is defined as the negative ratio of strain in the transverse direction to the strain in the axial direction. Although dimensionless, strain is sometimes expressed in units such as in./in. or mm/mm. In practice, the magnitude of measured strain is very small, so it is often expressed as microstrain (με), which is $\varepsilon \times 10^{-6}$.



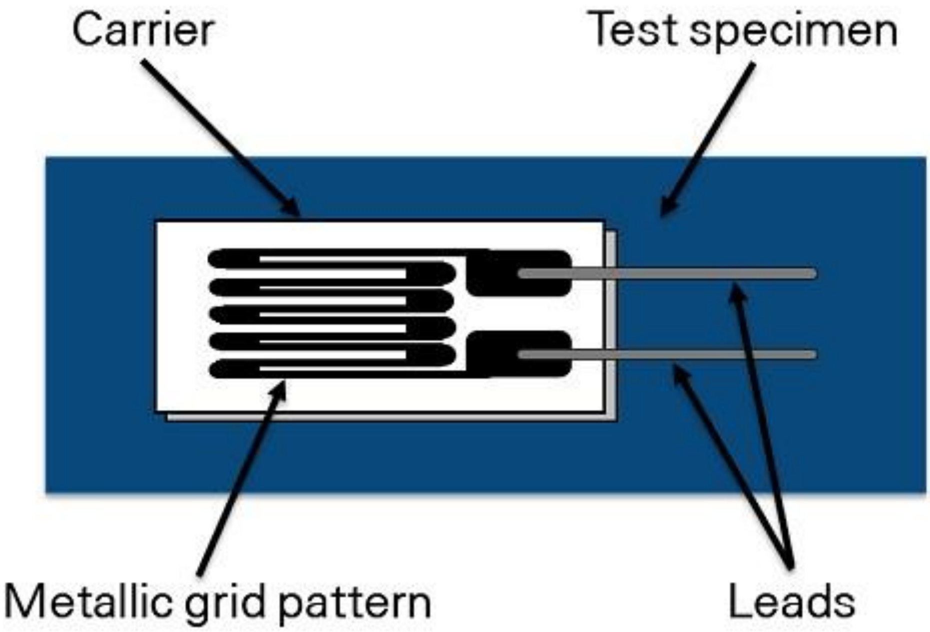
$$\varepsilon = \frac{\Delta L}{L}$$

The four different types of strain are axial, bending, shear, and torsional. Axial and bending strain are the most common (see Figure 2). Axial strain measures how a material stretches or compresses as a result of a linear force in the horizontal direction. Bending strain measures a stretch on one side of a material and the contraction on the opposite side due to the linear force applied in the vertical direction. Shear strain measures the amount of deformation that occurs from a linear force with components in both the horizontal and vertical directions. Torsional strain measures a circular force with components in both the vertical and horizontal directions.



Measuring Strain

Strain is commonly measured by a strain gage (sometimes written as "strain gauge"). A strain gage works by measuring its electrical resistance on the object subjected to an axial, bending, shear, or torsional force. Since electrical resistance varies in proportion to the amount of strain in the device as force is applied, it can be used to quantify strain. The most widely used strain gage is the bonded metallic strain gage. The metallic strain gage consists of a very fine wire or, more commonly, metallic foil arranged in a grid pattern. The grid pattern maximizes the amount of metallic wire or foil subject to strain in the parallel direction. The grid is bonded to a thin backing called the carrier, which is attached directly to the test specimen. Therefore, the strain experienced by the test specimen is transferred directly to the strain gage, which responds with a linear change in electrical resistance.



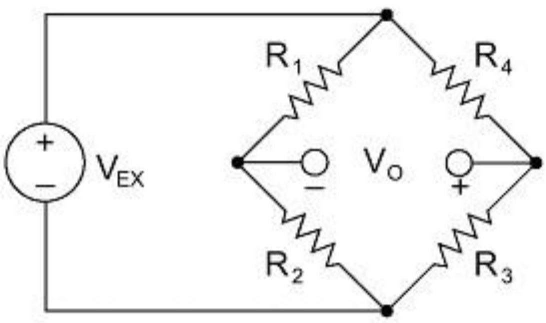
A fundamental parameter of the strain gage is its sensitivity to strain, expressed quantitatively as the gage factor (GF). GF is the ratio of the fractional change in electrical resistance to the fractional change in length, or strain:

$$GF = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon}$$

The GF for metallic strain gages is usually around 2. You can obtain the actual GF of a particular strain gage from the sensor vendor or sensor documentation.

In practice, strain measurements rarely involve quantities larger than a few millistrain (e x 10^{-3}). Therefore, to measure the strain, you have to accurately measure very small changes in resistance. For example, suppose a test specimen undergoes a strain of 500 me. A strain gage with a GF of 2 exhibits a change in electrical resistance of only 2 (500 x 10^{-6}) = 0.1%. For a 120 Ω gage, this is a change of only 0.12 Ω.

To measure such small changes in resistance, strain gage configurations are based on the concept of a Wheatstone bridge. The general Wheatstone bridge, illustrated in Figure 4, is a network of four resistive arms with an excitation voltage, VEX, that is applied across the bridge.



The Wheatstone bridge is the electrical equivalent of two parallel voltage divider circuits. R_1 and R_2 compose one voltage divider circuit, and R_4 and R_3 compose the second voltage divider circuit. The output of a Wheatstone bridge, Vo, is measured between the middle nodes of the two voltage dividers.

$$V_O = \left[\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + 2}\right] * V_{EX}$$

From this equation, you can see that when $R_1/R_2 = R_4/R_3$, the voltage output V_O is zero. Under these conditions, the bridge is said to be balanced. Any change in resistance in any arm of the bridge results in a nonzero output voltage. Therefore, if you replace R_4 in Figure 4 with an active strain gage, any changes in the strain gage resistance unbalance the bridge and produce a nonzero output voltage that is a function of strain.

Choosing the Right Strain Gage

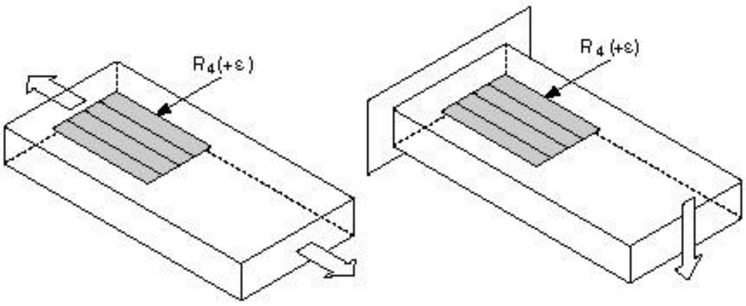
Types of Strain Gages

The three types of strain gage configurations, quarter-, half-, and full-bridge, are determined by the number of active elements in the Wheatstone bridge, the orientation of the strain gages, and the type of strain being measured.

1. Quarter-Bridge Strain Gage

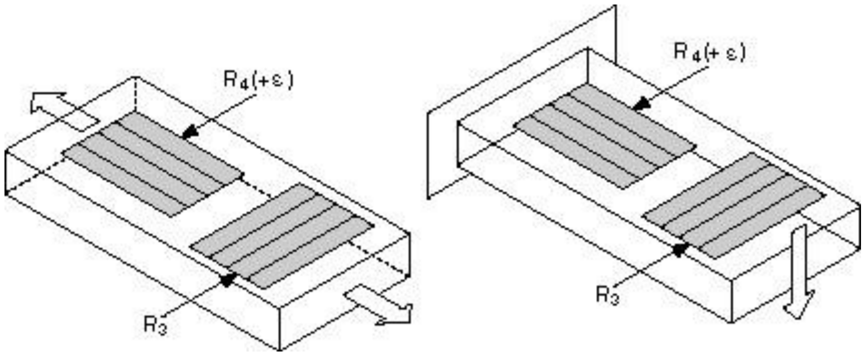
Configuration Type I

- Measures axial or bending strain
- Requires a passive quarter-bridge completion resistor known as a dummy resistor
- Requires half-bridge completion resistors to complete the Wheatstone bridge
- R4 is an active strain gage measuring the tensile strain (+ε)



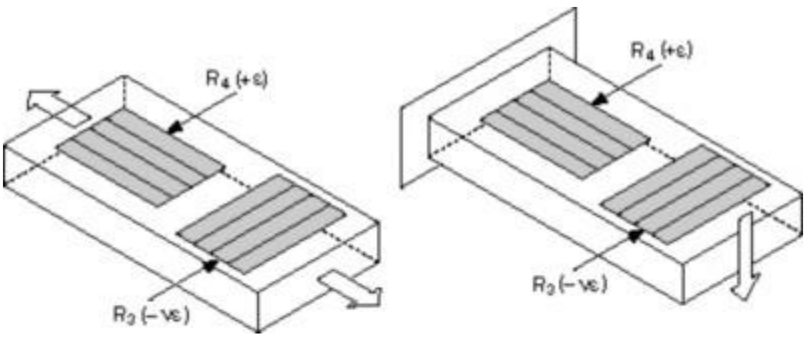
Configuration Type II

Ideally, the resistance of the strain gage should change only in response to applied strain. However, strain gage material, as well as the specimen material to which the gage is applied, also responds to changes in temperature. The quarter-bridge strain gage configuration type II helps further minimize the effect of temperature by using two strain gages in the bridge. As shown in Figure 6, typically one strain gage (R4) is active and a second strain gage (R3) is mounted in close thermal contact, but not bonded to the specimen and placed transverse to the principal axis of strain. Therefore, the strain has little effect on this dummy gage, but any temperature changes affect both gages in the same way. Because the temperature changes are identical in the two strain gages, the ratio of their resistance does not change, the output voltage (Vo) does not change, and the effects of temperature are minimized.



2. Half-Bridge Strain Gage

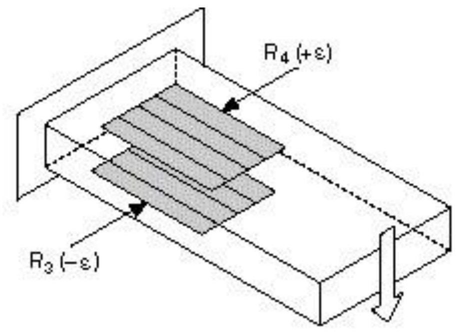
You can double the bridge's sensitivity to strain by making both strain gages active in a half-bridge configuration.



Configuration Type I

- Measures axial or bending strain
- Requires half-bridge completion resistors to complete the Wheatstone bridge
- R4 is an active strain gage measuring the tensile strain (+ε)
- R3 is an active strain gage compensating for Poisson's effect (-νε)

This configuration is commonly confused with the quarter-bridge type II configuration, but type I has an active R3 element that is bonded to the strain specimen.

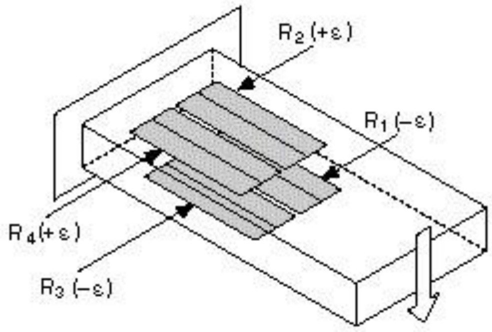


Configuration Type II

- Measures bending strain only
- Requires half-bridge completion resistors to complete the Wheatstone bridge
- R4 is an active strain gage measuring the tensile strain (+ε)
- R3 is an active strain gage measuring the compressive strain (-ε)

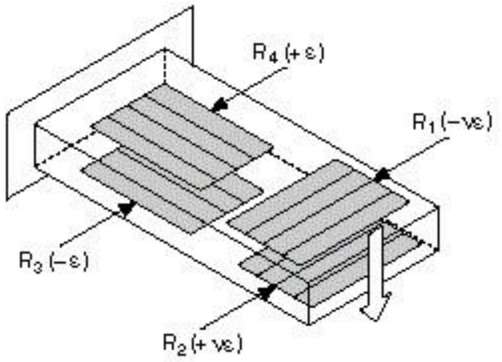
3. Full-Bridge Strain Gage

A full-bridge strain gage configuration has four active strain gages and is available in three different types. Types I and II measure bending strain and type III measures axial strain. Only types II and III compensate for the Poisson effect, but all three types minimize the effects of temperature.



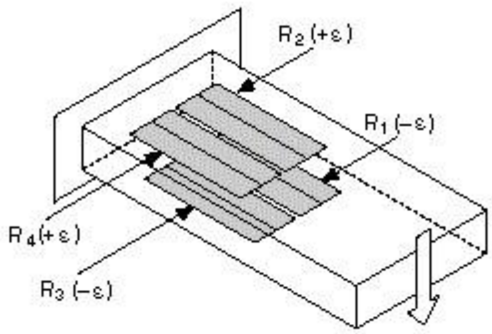
Configuration Type I: Only Bending Strain

- Highly sensitive to bending strain only
- R1 and R3 are active strain gages measuring compressive strain (–e)
- R2 and R4 are active strain gages measuring tensile strain (+e)



Configuration Type II

- Measures bending strain only
- Requires half-bridge completion resistors to complete the Wheatstone bridge
- R4 is an active strain gage measuring the tensile strain (+ε)
- R3 is an active strain gage measuring the compressive strain (-ε)
- R4 is an active strain gage measuring the tensile strain (+e)



Configuration Type III: Only Axial Strain

- Measures axial strain
- R1 and R3 are active strain gages measuring the compressive Poisson effect (–ve)
- R2 and R4 are active strain gages measuring the tensile strain (+e)

Specifications of Strain Gages to Consider

Once you have decided the type of strain you intend to measure (axial or bending), other considerations include sensitivity, cost, and operating conditions. For the same strain gage, changing the bridge configuration can improve its sensitivity to strain. For example, the full-bridge type I configuration is four times more sensitive than the quarter-bridge type I configuration. However, full-bridge type I requires three more strain gages than quarter-bridge type I. It also requires access to both sides of the gaged structure. Additionally, full-bridge strain gages are significantly more expensive than half-bridge and quarter-bridge gages. For a summary of the various types of strain gages.

Grid Width

Using a wider grid, if not limited by the installation site, improves heat dissipation and enhances strain gage stability. However, if the test specimen has severe strain gradients perpendicular to the primary axis of strain, consider using a narrow grid to minimize error from the effect of shear strain and Poisson strain.

Nominal Gage Resistance

Nominal gage resistance is the resistance of a strain gage in an unstrained position. You can obtain the nominal gage resistance of a particular gage from the sensor vendor or sensor documentation. The most common nominal resistance values of commercial strain gages are 120 Ω, 350 Ω, and 1000 Ω. Consider a higher nominal resistance to reduce the amount of heat generated by the excitation voltage. Higher nominal resistance also helps reduce signal variations caused by lead-wire changes in resistance due to temperature fluctuations.

Temperature Compensation

Ideally, strain gage resistance should change in response to strain only. However, a strain gage's resistivity and sensitivity also change with temperature, which leads to measurement errors. Strain gage manufacturers attempt to minimize sensitivity to temperature by processing the gage material to compensate for the thermal expansion of the specimen material for which the gage is intended. These temperature-compensated bridge configurations are more immune to temperature effects. Also consider using a configuration type that helps compensate for the effects of temperature fluctuations.

Installation

Installing strain gages can take a significant amount of time and resources, and the amount varies greatly depending on the bridge configuration. The number of bonded gages, number of wires, and mounting location all can affect the level of effort required for installation. Certain bridge configurations even require gage installation on opposite sides of a structure, which can be difficult or even impossible. Quarter-bridge type I is the simplest because it requires only one gage installation and two or three wires.

Signal Conditioning for Strain Gages

Strain gage measurements are complex, and several factors can affect measurement performance. Therefore, you need to properly select and use the bridge, signal conditioning, wiring, and DAQ components to generate reliable measurements. For example, resistance tolerances and strain induced by the application of the gage generate some initial offset voltage when no strain is applied. Similarly, long lead wires can add resistance to the arm of the bridge, which adds an offset error and desensitizes the output of the bridge. For accurate strain measurements, consider whether you need the following things:

- Bridge completion to complete the required circuitry for quarter- and half-bridge strain gages
- Excitation to power the Wheatstone bridge circuitry
- Remote sensing to compensate for errors in excitation voltage from long lead wires
- Amplification to increase measurement resolution and improve signal-to-noise ratio
- Filtering to remove external, high-frequency noise
- Offset nulling to balance the bridge to output 0 V when no strain is applied
- Shunt calibration to verify the output of the bridge to a known, expected value

Most important uses (Applications) of strain gauges

Strain gauges are extensively used in the field of geotechnical monitoring to keep a constant check on structures, dams, tunnels, and buildings so that mishaps can be avoided well on time. The applications of strain gauges include:

1. Aerospace

Strain gauges are fixed to the structural load-bearing components to measure stresses along load paths for wing deflection or deformation in an Aeroplan.

The strain gauges are wired into the Wheatstone Bridge circuits and, its application areas include onboard signal conditioning units, excitation power supplies, and the telemetry necessary to read in-site measurements.

2. Cable Bridges

Instrumentation of bridges is done to verify design parameters, evaluate the performance of new technologies used in the construction of bridges, verify and control the construction process, and for subsequent performance monitoring.

Well-instrumented bridges can alert responsible authorities about approaching failure to initiate preventive measures. Choosing proper sensor types, technology, a measurement range and their location on the bridge is very important to optimize costs and to extract the full benefits of instrumentation.

It becomes necessary to monitor the bridges regularly for any kind of deformation as it might lead to fatal accidents. Strain gauge technology is used in the real-time monitoring of huge bridges, making the inspections precise.

For example, the Yamuna Bridge in Allahabad-Naini is a 630-meter cable-stayed bridge across the river Yamuna. The bridge is installed with many measurement channels that sense wind speed and strain on its cables.

3. Rail Monitoring

Strain Gauges have a long history in the safety of rails. It is used to measure stress and strain on rails. Strain gauges measure axial tension or compression with no impact on the rails. In case of an emergency, the strain gauges can generate a warning so maintenance can be done early to minimize the impact on rail traffic.

Resource:

- https://www.ni.com/en/shop/data-acquisition/sensor-fundamentals/measuring-strain-with-strain-gages
- https://www.dwyeromega.com/en-us/resources/strain-gages
- https://www.bu.edu/moss/mechanics-of-materials-strain/
- https://byjus.com/physics/stress-and-strain/
- https://www.corrosionpedia.com/definition/6405/engineering-strain
- https://www.sciencedirect.com/topics/engineering/mechanical-strain
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- https://www.encardio.com/blog/strain-gauge-principle-types-features-and-applications